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Leaf Area Indices and Nitrogen Uptake of Flue-Cured Tobacco as Affected by Plant Density and Nitrogen Rate[1]

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ABSTRACT

Effects of three plant densities and two nitrogen rates on leaf areas and nitrogen uptake by tobacco plants were studied during 1961 and 1962. A study was also made on the economics of these treatments.

Leaf area indices (LAI's) for both years increased with time until the reduction in total leaf area through loss of senescent lower leaves became greater than the gain in leaf area of the active upper leaves. The highest maximum LAI of 5 in 1961 was obtained for the high nitrogen rate and the 25-cm spacing. The lowest maximum LAI of 2.5 was obtained for the low nitrogen rate and the 76-cm spacing. LAI's increased with high nitrogen and at both levels of nitrogen the LAI's were in the order of 25 > 51 > 76-cm spacings in 122-cm beds.

Relationships between leaf area and leaf weight per plant were very similar during 1961 and 1962. Correlation coefficients for leaf areas and weights varied from 0.95 to 0.99 in 1961 and from 0.92 to 0.99 in 1962. In both years, better correlation appeared between leaf areas and weights at the high nitrogen rate than at the low nitrogen rate, with spacing treatments having little effect on the relationships.

Nitrogen uptake was much higher with the high nitrogen treatment than with the low nitrogen treatment.

The yield of flue-cured tobacco increased with closer plant spacing and the higher nitrogen rate. However, leaf quality decreased with the high nitrogen rate and offset the higher yields in total dollar value per hectare. The quality of tobacco appeared to be influenced more by the nitrogen application than by the different plant spacings. The most profitable treatment combination appeared to be the 76-cm spacing at the low nitrogen rate.

Additional index words: leaf area, nitrogen, tobacco, plant density.

THE photosynthesis rate of green leaves is affected by many complex, interacting factors as pointed out by Monteith (10) and de Wit (6). Even the measurement of the light received by plant communities is very complex, according to Anderson (1). An important factor affecting the photosynthesis rate is the leaf area of the plants. An early increase in leaf area could increase the potential crop yield. Watson (14, 15) and Nichiporovich (11) reported comprehensively on leaf area of crops and its relationship to yield. Differences in leaf area per unit land area correlated with dry matter accumulation for wheat, barley, potatoes, and sugar beets (14). Interpretation of LAI data in terms of photosynthetic actions and reactions will be possible when measurements are made for that part of the spectrum affecting photosynthesis by leaves.

Some research workers correlate leaf area of crops and factors involved in or influencing the growth processes of plants. Schwabe (12) found that leaf areas of *Xanthium pennsylvanicum* (cocklebur) and *Beta vulgaris* (sugarbeet) decreased markedly under conditions of continuous light. Blackman (4) reported that shading 10 different plant species resulted in changes in the net assimilation rate and leaf area ratio which were linearly related to the log of the light intensity. Consequently, this gave a curvilinear relationship between the relative growth rate and the log of the light intensity. Brougham (5) found high correlations among leaf area, chlorophyll content, and growth rate of a number of crops. A relationship between leaf area and total fruiting of cotton was found in Alabama by Ashley et al. (2). LAI's for corn increased with increased number of plants per hill, as reported by Eisele (9). In studying various factors affecting leaves of corn, Eik and Hanway (8) found that starter fertilizer (22N–4P–16K) consistently increased the rate of expansion of total leaf area when no plow-under fertilizer was used. A greater leaf area response was noted with a higher nitrogen content in the starter fertilizer.

During much of the life of annual crops, LAI has very low values. Theoretically, when the LAI is less than 1, some of the incident solar radiation will be directly intercepted by the land. Even under actual conditions when the LAI is greater than 1, only part of the solar radiation is intercepted by the plant leaves; the other part is intercepted by the soil between the plants. This situation partially accounts for the early low efficiency of solar energy utilization. Sufficient fertilization and closer plant spacing could shorten the low LAI period and hasten development of high LAI. According to Nichiporovich (11), the objectives for increased crop yields per unit land area are to insure an early development of maximum possible leaf area and to create optimum conditions for photosynthetic activity by the plants.

Despite much research on tobacco plants, more information about relationships among leaf area, dry matter production, and nitrogen uptake is necessary to obtain higher efficiency and more profitable yields. These experiments were conducted to study the effects of nitrogen and plant spacing on tobacco leaf area and nitrogen uptake by the plants.

PROCEDURE

Tobacco (*Nicotiana tabacum* L. var. 'Hicks Broadleaf') was transplanted into a randomized complete block arrangement. The main plot treatments were plant spacings of 25, 51, and 76 cm on 122-cm beds. These spacings gave 32,292, 16,146, and 10,764 plants per ha, respectively. The split-plot treatments were two levels of nitrogen, 45 and 135 kg/ha. Six replications were included in 1961 and in 1962. The whole plots in 1961 were 10 m wide and 18 m long; split plots were the same width but only 9 m long. Whole plots in 1962 were 22 m wide and 9 m long; the split plots were the same length but 11 m wide. Plot sizes were large enough to supply plants for sampling throughout the growing season.

The experiments were located on a Coastal Plain soil, Marlboro fine sandy loam, at the Pee Dee Experiment Station near Florence, S. C. The soil had a pH of 5.8. Tobacco fertilizer (45N-40P-112K) was applied initially in the row prior to transplanting, and additional fertilizer containing 56 kg of K/ha from potassium sulfate was sidedressed about May 31 each year. Half of each main plot received an extra 90 kg/ha of N as sodium nitrate on June 1.

Length and width measurements of all leaves on six randomly selected tobacco plants in each split plot were taken at 2-week intervals from transplanting until August 9, 1961, and until August 15, 1962. Whole plant samples were taken during the same time periods. Dry weights and total nitrogen contents (3) were determined on the tobacco leaves of these samples.

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Methods of leaf area measurements have been proposed by Eisele (9), Donovan et al. (7), Suggs et al. (13), and others. The Suggs technique (13) was used in this study because it is simple, rapid, and specific for tobacco leaves. The relative leaf areas, calculated by the Suggs formula, are as follows: Area = b (length) (width), in which the coefficient b was 0.7028 for tobacco leaves of 203 cm^2 or less, and was 0.6203 for leaves greater than 203 cm^2. Leaf areas were calculated from more than 10,000 leaf measurements made on the same plants in each experiment during the growing season. Total leaf dry weights were obtained from approximately 700 randomly selected tobacco plants in each experiment using the destructive sampling technique.

Originally, a set of equations was obtained which in each instance caused the predictive curves to dip below the X-axis (giving negative values for leaf area index which is physically impossible) in the interval beween the first and second observations. These equations were of the form,

$$LAI = b_0 + b_1X + b_2X^2 + b_3X^3 + b_4X^4$$

where $b_i \neq 0$, $i = 0,1,2,3,4$, and X is the number of days from the first observation. This dip was caused by negative slopes for the linear components of the equation. Therefore, it was necessary to derive new equations which eliminated these linear components.

This new set of equations was of the form,

$$LAI = b_2X^2 + b_3X^3 + b_4X^4$$

From these equations it was found that either the X^2 term, X^3 term, or X^4 term could be deleted since they added no new information. Thus, we have the equations which are presented later in the paper. These equations were used in plotting the smooth curves in the figures. The actual measurement data are plotted points.

RESULTS AND DISCUSSION

Leaf Area Indices

Examples of the predictive equations used to plot the smooth curves in the figures are listed below. In each equation "X" is the number of days after transplanting. For 1961, 45 kg nitrogen/ha, 25-cm spacing:

$$LAI = .0013092439X^2 - .0000001183141X^4$$

$$\%N = 2.4634 + .29816X - .012137X^2 + .0001559X^3 - .0000006533X^4$$

$$\text{Kg N/ha} = .021795568X^2 - .00020018665X^3$$

In 1961, the LAI's for each spacing and each nitrogen treatment remained less than 0.5 until after the 29th day after transplanting. Thereafter, the LAI's increased rapidly toward maximum values of 2.4 to 5.0 as shown in Fig. 1-A, 1-B, 1-C, 1-G, and 1-H. Maximum LAI's were obtained on the 61st day after transplanting for the 25- and 51-cm spacings at both nitrogen levels, and about 10 days later for the 76-cm spacing at both nitrogen levels. The

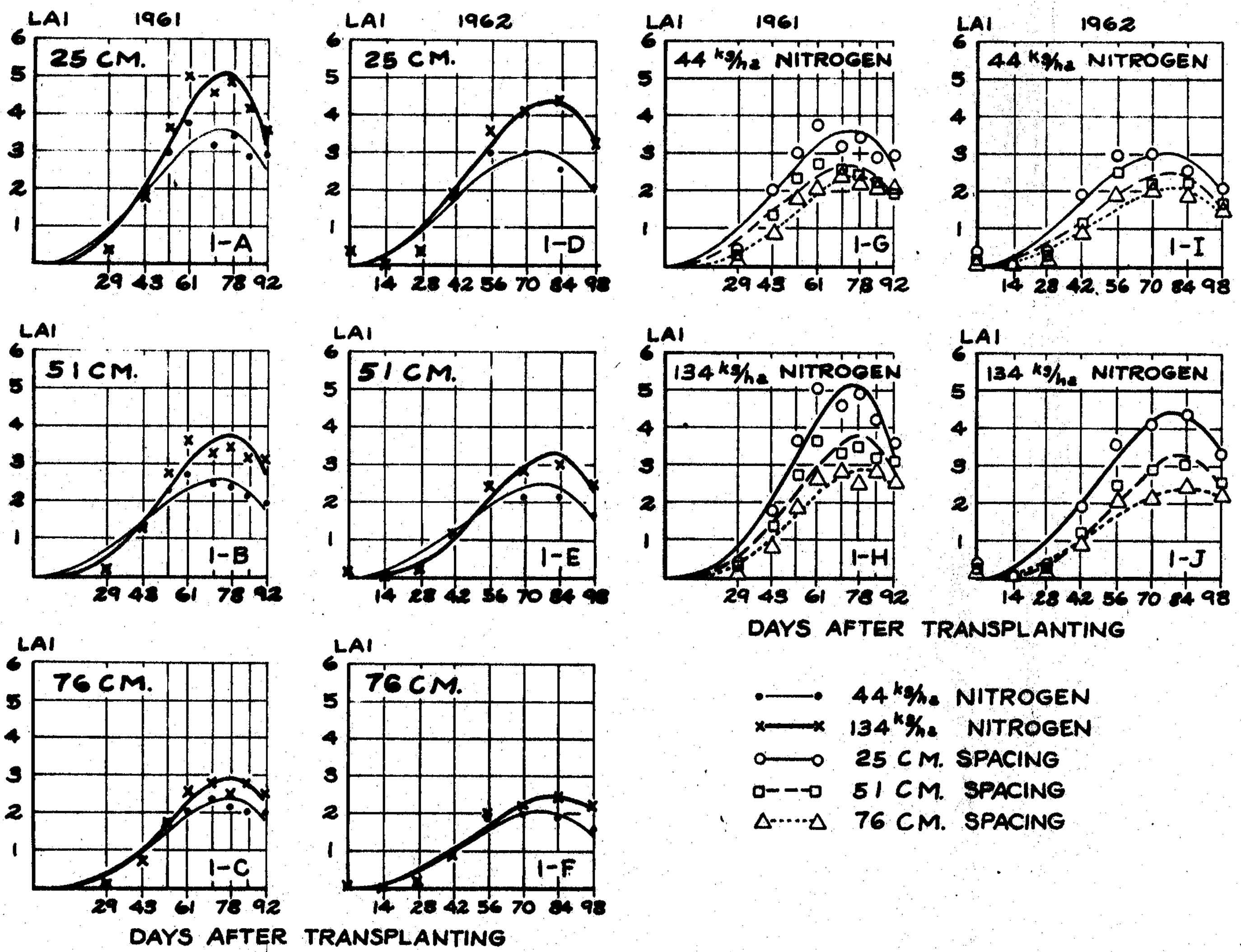

Fig. 1. Relationship of leaf area index with number of days after transplanting of tobacco planted in 25-, 51-, and 76-cm spacings and fertilized with 45 and 134 kg of N/ha.

effect of the higher nitrogen treatment on LAI's was not evident until the 53rd day after transplanting for the 25- and 51-cm spacings and the 61st day for the 76-cm spacing. Although nitrogen treatments did not appear to affect the LAI's during these periods of rapid LAI increase, the nitrogen percentages in the leaves reflected the nitrogen treatments, as can be seen by studying Fig. 2-A, 2-B, and 2-C. Apparently, the lower rate of nitrogen (45 kg/ha) plus the residual soil nitrogen were sufficient to sustain comparable LAI increases for the 25- and 51-cm spacing until after the 43rd day, and for the 76-cm spacing until after the 53rd day after transplanting.

Prior to the 43rd day, 6.6 cm of precipitation fell, and 10.1 cm of precipitation fell before the 53rd day after transplanting. Following the 43rd day, the LAI's for the 25- and 51-cm spaced plants receiving the high nitrogen treatment increased more rapidly toward the maximum than did those plants with the low nitrogen treatment. Similar results occurred in the 76-cm spacing after the 53rd day.

Regardless of treatment, LAI's generally increased with time until the reduction in total leaf area, from loss of senescent lower leaves, became greater than the gain in leaf area through expansion of upper leaves. The highest maximum LAI was obtained for a 135-kg nitrogen rate in the 25-cm spacing. The lowest maximum LAI was found for the 45-kg nitrogen rate in the 76-cm spacing. In all spacing treatments, the plots receiving the higher nitrogen treatment also showed the higher LAI's. This is illustrated in Fig. 1-A, 1-B, and 1-C. At both levels of nitrogen, the LAI's were in the general order of 25-cm spacing > 51-cm spacing > 76-cm spacing as illustrated in Fig. 1-G and 1-H.

Differences among LAI's of treatments during the maximum plant growth period for 1961 are given in the first part of Table 1. Greater differences for higher nitrogen treatment were found between the 25-cm spacing and the other spacings. The 71st day after transplanting marked the end of a short period of plant moisture stress, manifested by leaf area reduction (Fig. 1-G and 1-H) and lack of differences due to spacings.

A study was made using the 1961 data of the relationship between leaf areas and leaf dry weights per plant. Correlation coefficients for leaf areas with leaf weights, all highly significant, varied from 0.95 to 0.99. A better correlation between leaf area and leaf weight existed at the

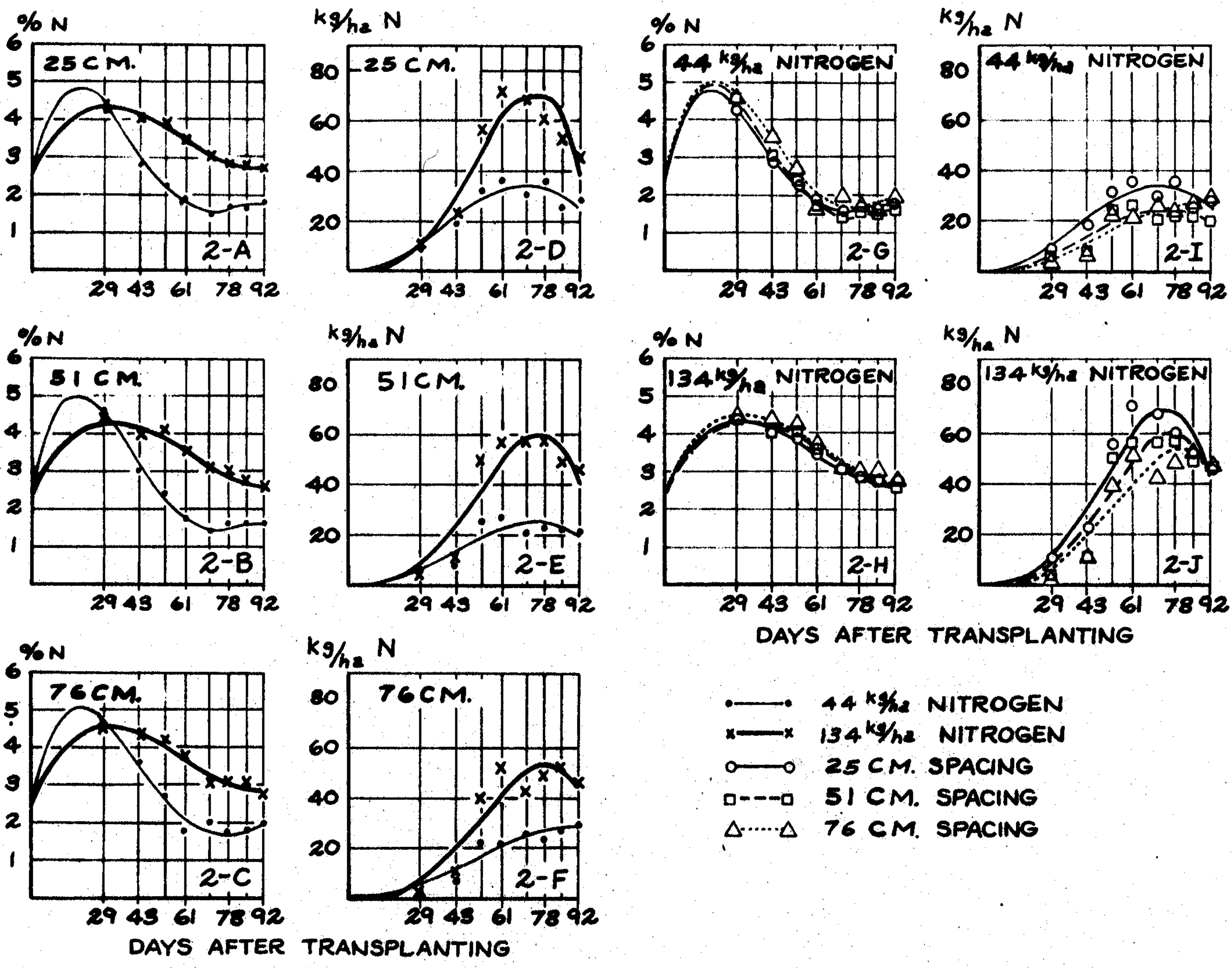

Fig. 2. Relationship of N content in leaves and N uptake by plants with the number of days after transplanting of tobacco planted in different spacings and fertilized with two rates of N.

Table 1. Differences among the leaf area indices for three plant spacings at two nitrogen levels for different measurement dates.

Measurement dates	45 kg N/ha Spacing, cm			134 kg N/ha Spacing, cm		
	25 vs 76	25 vs 51	51 vs 76	25 vs 76	25 vs 51	51 vs 76
				1961		
7/1	*	ns	ns	**	ns	ns
7/9	**	*	ns	**	**	*
7/19	ns	ns	ns	**	*	ns
7/26	*	*	ns	**	**	*
8/1	ns	ns	ns	*	*	ns
				1962		
6/20	**	**	ns	**	**	ns
7/4	**	*	**	**	**	*
7/18	**	**	ns	**	**	**
8/1	**	ns	ns	**	**	*

* and ** indicate significant differences at 5% and 1% levels, respectively.
ns = not significant at 5% level of probability.

high nitrogen treatment for all spacings than at the low nitrogen level.

In 1962 LAI's appeared to be quite comparable to those found the previous year. This can be seen by comparing Fig. 1-D, 1-E, 1-F, 1-I, and 1-J for 1962 with Fig. 1-A, 1-B, 1-C, 1-G, and 1-H for 1961. Consequently, trends similar to those found in 1961 will not be discussed for 1962. In all instances maximum LAI's obtained in 1961 were higher than those in 1962 when compared within corresponding nitrogen and spacing treatments. Maximum LAI's at the low nitrogen level for all spacings in 1962 occurred at approximately the same date as in 1961. At the high nitrogen level and at all spacings, maximum LAI's in 1962 occurred about the 84th day, somewhat later than in 1961.

Differences among the leaf area indices during the period of most rapid growth in 1962 are given in the last part of Table 1. Differences between any two spacings were more often significant in 1962 than in 1961.

Relationships between leaf areas per plant and leaf weights per plant for 1962 were similar to those found in 1961. The correlation coefficients for leaf areas with leaf weights varied from 0.92 to 0.99 and were all highly significant. As in 1961, there was a better correlation between leaf area and leaf weight at the higher nitrogen rate for all spacings than at the low nitrogen rate.

Nitrogen Uptake

The percentage of nitrogen in tobacco leaves for the two nitrogen treatments in 1961 is shown in Fig. 2-A, 2-B, 2-C, 2-G, and 2-H. The greatest increase in nitrogen content of leaves occurred between the transplanting date and the 29th day after transplanting. After the 29th day, leaf nitrogen content decreased for all treatments, probably because of nitrogen dilution through increased leaf growth.

Figures 2-D, 2-E, 2-F, 2-I, and 2-J show the uptake of nitrogen by the tobacco plants in kg/ha. The largest amounts of nitrogen taken up by the plants, regardless of treatment, occurred about the 61st day after transplanting and coincided with the greatest increase in leaf weights. Low rainfall preceding the 53rd day may have reduced nitrogen uptake until just before the 53rd day. Figures 2-D, 2-E, and 2-F show that the higher nitrogen treatment resulted in much higher maximum nitrogen uptake values.

Economics

Because this experiment was not designed to study yield and quality of flue-cured tobacco, in 1961 cropping of the leaves was conducted only in a 51-cm spacing area at the two nitrogen levels outside the experiment. Results showed that the tobacco at the low nitrogen rate matured 1 week sooner and was of higher quality than that grown at the high nitrogen rate.

In 1962, the economics involved in the various treatments of the experiment were studied. The yield of flue-cured tobacco increased with closer plant spacing and with the higher nitrogen rate. However, the leaf quality decreased with the higher nitrogen rate and somewhat offset the higher yields in dollar value. The highest mean yields of 2,047 and 2,199 kg/ha were obtained for the 25-cm spacing at the low and high nitrogen rates, respectively. The lowest mean yield of 1,849 kg/ha was obtained for the 76-cm spacings at both nitrogen rates and for the 51-cm spacing at the low nitrogen rate. The yield of flue-cured tobacco for the 51-cm spacing at the high nitrogen rate was intermediate at 2,030 kg/ha. The quality of tobacco appeared to be influenced more by nitrogen than by the plant spacings. The dollar values per .4536 kg were $57.34, $59.01, and $60.47 for the 25-, 51-, and 76-cm spacings at the low nitrogen rate, and were $45.92, $47.04, and $45.63 for the 25-, 51-, and 76-cm spacings at the high nitrogen level. Gross income per ha was about the same for all spacings at the low nitrogen rate but decreased with increasing spacing at the high nitrogen rate. Income per ha varied from 10 to 25% lower at the high nitrogen rate for all spacings.

Based on the gross dollar income per ha minus the cost of planting, suckering, topping, and other practices associated with flue-cured tobacco production, the 76-cm spacing at the low nitrogen rate appeared to be the most profitable treatment combination in this experiment.

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